

WP13 (NA2-Small-x): *Small-x Physics at the LHC and future DIS experiments*

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Plan of the presentation:

1. Introduction

2. Progress made during the year towards the objectives

3. Deliverables and milestones

4. Other significant achievements

5. Budget

Introduction:

- Initially 15 institutions; several additional contacts:
 - B. Blok (Technion)
 - G. Chachamis (LIP)
 - M. Hentschinski (Puebla)
 - C. Royon (KU)
 - W. Xiang (Guizhou University)
- Online meetings: 7 this year (8th scheduled December 3rd), ~25 participants, see <https://indico.cern.ch/category/10863/>.

Participant institutions:

- **BGU**: Ben-Gurion University of the Negev, Beer Sheva, Israel ([M. Lublinsky](#)).
- **CNRS**: École Polytechnique, Université Paris-Saclay, Palaiseau, France ([C. Marquet](#), [S. Munier](#)) + IPhT, Commissariat à l'énergie atomique, Saclay, France ([F. Gelis](#), [E. Iancu](#), [G. Soyez](#)) + Laboratoire de Physique Théorique, Université Paris-Saclay, Orsay, France ([S. Wallon](#)).
- **Consenza**: Università della Calabria, Cosenza, Italia ([A. Papa](#)).
- **CTU**: Czech Technical University, Prague, Czech Republic ([J. Cepila](#), [G. Contreras](#)).
- **ECT***, Trento, Italy ([D. Triantafyllopoulos](#)).
- **Firenze**: Università de Firenze, Italia ([D. Colferai](#)).
- **Granada**: Universidad de Granada, Spain ([J. L. Albacete](#)).
- **Groningen**: University of Groningen, The Netherlands ([D. Boer](#)).
- **Jyväskylä**: University of Jyväskylä, Finland ([T. Lappi](#), [H. Paukkunen](#), [K. J. Eskola](#)).
- **Krakow INP**: Henryk Niewodniczański Institute of Nuclear Physics, Krakow, Poland ([K. Golec-Biernat](#), [K. Kutak](#), [S. Sapeta](#)).
- **Krakow JU**: Jagiellonian University, Krakow, Poland ([Leszek Motyka](#), [Michal Praszalowicz](#)).
- **Madrid**: Universidad Autónoma de Madrid, Spain ([A. Sabio Vera](#)).
- **Regensburg**: University of Regensburg, Germany ([G. Chirilli](#)).
- **Santiago**: Universidade de Santiago de Compostela, Spain ([N. Armesto](#)).
- **Warsaw**: National Centre for Nuclear Research, Warsaw, Poland ([T. Altinoluk](#), [L. Szymanowski](#)).

- Workshop at ECT*: 63 participants, 30 talks:

<https://indico.ectstar.eu/event/84>.

- Next year:

SATURATION AND DIFFRACTION AT THE LHC AND THE EIC

27 June 2022 — 01 July 2022 Hybrid/Mixed

The general scientific goal of this workshop is related to QCD at high gluon densities and diffraction at the Large Hadron Collider (LHC) and the future Electron-Ion Collider (EIC) to be built in the US either at JLab or at BNL.

Saturation and Diffraction at the LHC and the EIC

29 June 2021 to 1 July 2021
Online
Europe/Rome timezone

Overview

List of Participants

Contribution List

Timetable

Data Protection

... FBK Policy

Contact: Staff ECT*

✉ staff@ectstar.eu

[Saturation and Diffraction at the LHC and the EIC](#)

The general scientific goal of this workshop is related to QCD at high gluon densities and diffraction at the Large Hadron Collider (LHC) and the future Electron-Ion Collider (EIC) to be built in the US at BNL.

The goals of the workshop are twofolds. We intend to define the best observables sensitive to BFKL resummation effects at low x and the way to see saturation at the LHC and the EIC. Many LHC data have been accumulated in the different experiments, and it is also worth to explore the difference between the general ATLAS and CMS experiments and the specificities of Alice and LHCb allowing to run at lower pile up or with a lower cut on track momentum. The complementarity between the different experiments is an important tool to be discussed in order to reach the best possible sensitivity to saturation effects. Related to this topic is the important aspect of building the best detector possible at the EIC to be sensitive to these effects (by measuring hadrons in the very forward region as an example) since it is now time to define the detectors for the EIC.

The second topic deals with diffraction at the LHC and the EIC and a better understanding of the Pomeron models and structures. Following the experience at HERA and the Tevatron, it is useful to define the best possible measurements to be performed at the LHC and then the EIC to get a better insight into diffraction. Measurement different productions of jets, photons, vector mesons and disentangling these measurements from survival probability effects is crucial.

Progress made:

Task 1: Nuclear PDFs.

- Progress to include new LHC run 2 data in nuclear PDF fits: new dijet and EW boson data, D-meson production and of high-x CLAS data, plus uncertainties in the proton baseline (USC-JYU).
- Studies of the prospects for determination of nPDFs and DPDFs at future DIS experiments: LHeC/FCC-eh and EIC (YR [2103.05419](#)) (USC-JYU).

Progress made:

Task 2: New NLO-based precision phenomenology in CGC and BFKL.

- Technical aspects in the CGC:
 - Massive quarks in the dipole model at NLO, needed for new resummed-NLO fits to HERA HQ inclusive DIS data (JYU-NCBJ, [2103.14549](#)).
 - Non-eikonal corrections (NCBJ, [2109.01620](#) , [2012.03886](#); Regensburg, [2101.12744](#)).
 - Real corrections to forward dijet production in pA at NLO (IPhT-JYU, [2009.11930](#)).
 - Systematics in numerical solutions of JIMWLK (JU-INP-CPhT, [2104.14254](#)).

Progress made:

Task 2: New NLO-based precision phenomenology in CGC and BFKL.

- NLO BFKL phenomenological analysis: for the production of heavy quark pairs, Λ_c , heavy-light dijets, H+jet in pp ([2109.11875](#), [2105.06432](#), [2103.07396](#), [2008.00501](#)) and of VM in DIS ([2107.13415](#)) (Consenza); for forward Higgs production (INP, [2011.03193](#)).
- Multijet production in the high energy limit (UAM-LIP, [2106.11255](#), [2012.09664](#)); central-forward dijets (INP, [2010.13066](#)).
- Diphoton production at NLO (CPhT-NCBJ, [2110.00048](#)).
- Electron-dijet correlations at the EIC (INP, [2106.13964](#)).
- Diffraction in future EICs (CTU, [2009.14002](#)).
- Saturation effects in SIDIS at forward rapidities (IPhT-ECT*, [2012.08562](#)).
- Forward photon production in pp as a test of parton scattering (INP-JU, [2010.00468](#)).

Progress made:

Task 3: TMDs at small x (relation with JRA4 and JRA5)

- iTMD approach to heavy quark production in ep and pp (CPhT-NCBJ, [2103.14495](#)).
- Kinematic twists and saturation in dijet production in DIS (CPhT-JYU, [2106.11301](#)).
- Diffractive and CC electroproduction at an EIC (CPhT-NCBJ, [2103.01411](#), [2104.04944](#)).
- Diffractive dijet and quarkonium production at the EIC (Groningen, [2106.15148](#), [2102.00003](#)).

Progress made:

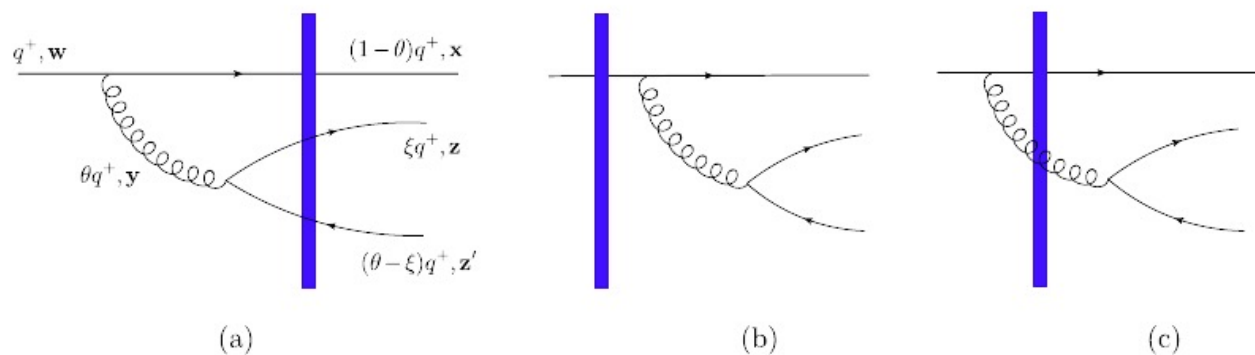
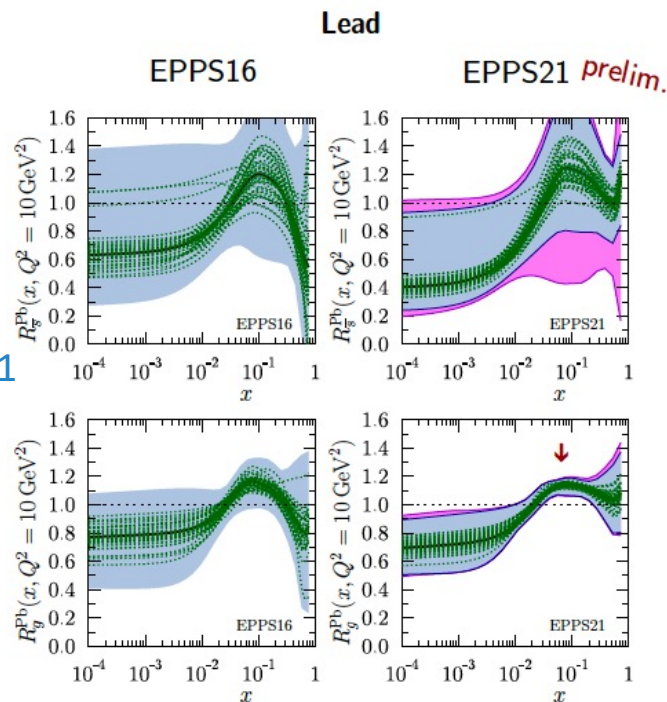
Task 4: Multi-particle correlations & Thermalization.

- Heavy ion phenomenology: building a realistic distribution of matter created in heavy ion collisions, including fluctuations (JYU, [2102.09993](#), [2101.03791](#)).
- Proton colour structure beyond MV (JYU, [2103.11682](#), [2106.12623](#)).
- Understanding the universal behaviour and the transport coefficients in an over-occupied gluon plasma (JYU, [2106.11319](#), [2101.02715](#)).
- Multiparticle correlations in the CGC, up to 4 particles (USC-NCBJ, [2103.08485](#)); v_2 - $\langle p_T \rangle$ and v_2 - $\langle N \rangle$ correlations (BGU-NCBJ-USC, [2012.01810](#)).
- Light-cone description for jet quenching (JYU, [2107.02225](#)) and evolution equations (USC-CPhT, [2101.12135](#); INP-JU, [2109.05918](#), [2009.03876](#)).
- Parton distributions in the proton and entanglement (INP, [2110.06156](#)).

Some highlights:

Task 1: Work ongoing to include new LHC run 2 data plus proton baseline uncertainties in nuclear PDF: EPPS21 (USC-JYU).

Task 2: real corrections to forward dijet production in pA as a step towards full result (virtual corrections ongoing) (IPhT-JYU).



Iancu, Mulian, 2209.11930

P. Paakinen at DIS2021

Some highlights:

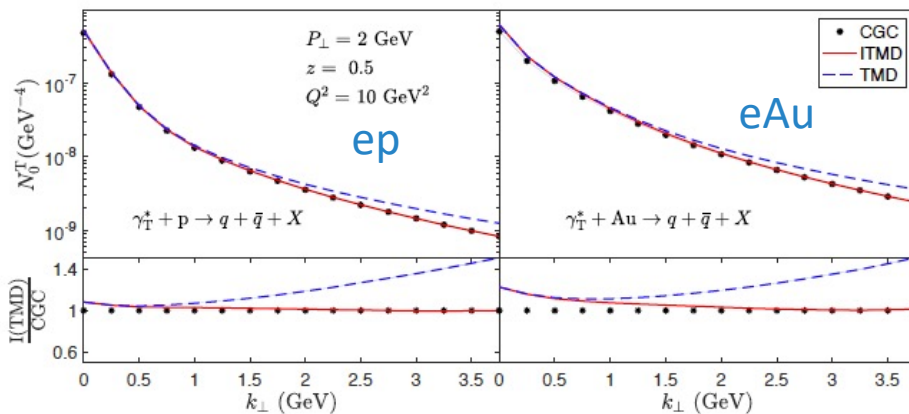
Task 3: Interplay between kinematic twists and saturation in dijet production in DIS (CPhT-JYU).

$$d\sigma_{\text{CGC}} = \underbrace{d\sigma_{\text{TMD}}}_{\text{kinematic}} + \mathcal{O}\left(\frac{k_{\perp}}{Q_{\perp}}\right) + \mathcal{O}\left(\frac{Q_s}{Q_{\perp}}\right) \quad \underbrace{\text{genuine}}$$

$$k_{\perp} = k_{1\perp} + k_{2\perp}$$

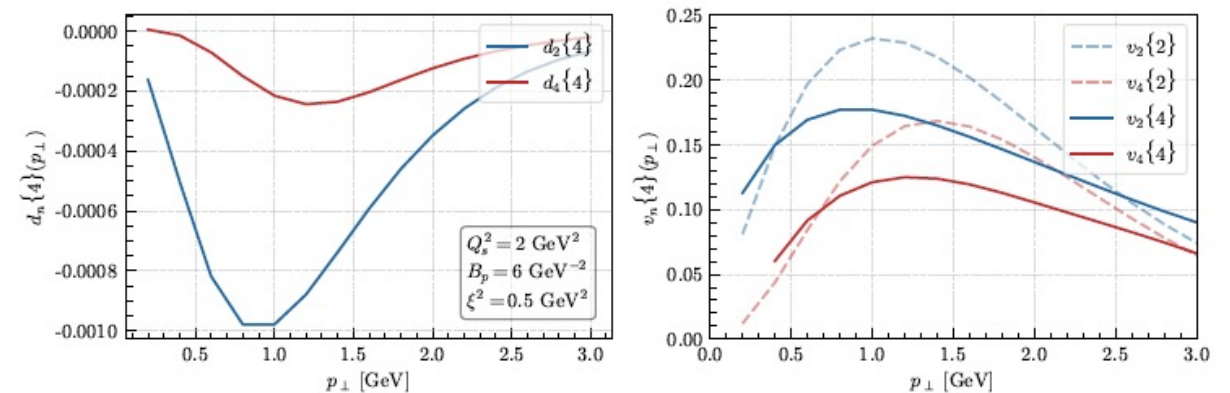
$$P_{\perp} = z_2 k_{1\perp} - z_1 k_{2\perp}$$

Boussarie, Mantysaari, et al., 2106.11301



Task 4: Multiparticle correlations in the CGC, up to 4 particles, connection with the Wigner function (USC-NCBJ).

Agostini, Altinoluk, Armesto, 2103.08485



Deliverables and milestones:

Deliverable Number ¹⁴	Deliverable Title	Lead beneficiary	Type ¹⁵	Dissemination level ¹⁶	Due Date (in months) ¹⁷
D13.1	NPDFs	23 - JYU	Report	Public	48
D13.2	Resummed NLO cross sections	1 - CNRS	Report	Public	36
D13.3	TMD factorization	37 - IFJ PAN	Report	Public	48
D13.4	Initial vs final state correlations	20 - USC	Report	Public	36

MS11	Reweighting of nPDFs including new LHC data	WP13	20 - USC	24	Publications and presentations in conferences, and software released and validated by a user group
MS12	Dipole cross section from resummed JIMWLK evolution	WP13	20 - USC	24	Publications and presentations in conferences, and software released and validated by a user group
MS13	TMD factorization at small x for 3 final-state particles	WP13	20 - USC	24	Publications and presentations in conferences
MS14	Completion of the calculation of multi-particle correlations in the dilute limit of the CGC	WP13	20 - USC	24	Publications and presentations in conferences

MS11 Reweighting of nPDFs including new LHC data

Achieved: inclusion of D-mesons and dijets; a release of the code (EPPS21) in preparation.

MS12 Dipole cross section from resummed JIMWLK evolution

Achieved: final fit and check of the small size of N_c corrections; code released.

MS13 TMD factorization at small x for 3 final-state particles

Almost achieved: done for 3 jets in proton-nucleus collisions, lacks the TMD analysis; done for photon plus two jets, in photoproduction and also in proton-nucleus collisions.

MS14 Completion of the calculation of multi-particle correlations in the dilute limit of the CGC

Achieved: 2 to 4-gluon correlations in proton-nucleus collisions; v_2 -multiplicity and transverse momentum correlations; non-eikonal corrections in proton-proton collisions; comparison of CGC and iTMD for 2-particle correlations; angular correlations of quarkonia.

No deviations from planned found.

Other significant achievements:

Strong implication in future experimental programmes:

- Quarkonium at HL-LHC ([2012.14161](#)).
- Yellow report of the EIC ([2103.05419](#)), both at organisational level and contributing with material.

Use of financial resources:

- **Travel costs** frozen by the **COVID** situation. Travels to this meeting from INP (also 2019) and USC.
- **Two joint postdocs** planned in the activity (USC- JYU: Florian Cougoulic; CNRS-INP: Victor Vila) started their contracts in October/November 2020, salaries **were covered initially by other grants** that have to be employed to complement the STRONG-2020 contribution. Florian Cougoulic to USC in May 2022, Victor Vila to INP now.

Institution	Original	Final
CNRS (Polytechnique, LPT Orsay, Saclay)	0	12000
ECT*	0	2000
Firenze	0	2000
Jyvaskyla	32000	16000
Krakow INP	0	6000
Krakow JU	0	4000
Regensburg	0	2000
Santiago de Compostela	32000	16000
NCBJ Warsaw	0	4000
Total	64000	64000

SmallX						
REQUESTED EC CONTRIBUTION PER BUDGETARY ITEM AND PER BENEFICIARY						
Contr. No	Contractor Acronym	Personnel (EUR)	Other costs (durables, consumables, travel, workshops) (EUR)	Total direct costs (EUR)	Indirect costs (EUR)	Requested EC contribution (EUR)
	Santiago	25000	32000	57000	14250	71250
	Jyväskylä	25000	32000	57000	14250	71250
	CNRS	50000		50000	12500	62500
	Warsaw/Krakow	20000		20000	5000	25000
	TOTAL	120000	64000	184000	46000	230000

Summary:

- Activities go well in all tasks despite COVID.
- Milestones and deliverables progress very well.
- Negligible use of travel financial resources until now: Grant Agreement modification, COVID situation. Postdoc hiring goes as planned.
- Regular activities online. In-person workshops and travel activities to be restarted as soon as the COVID situation allows.